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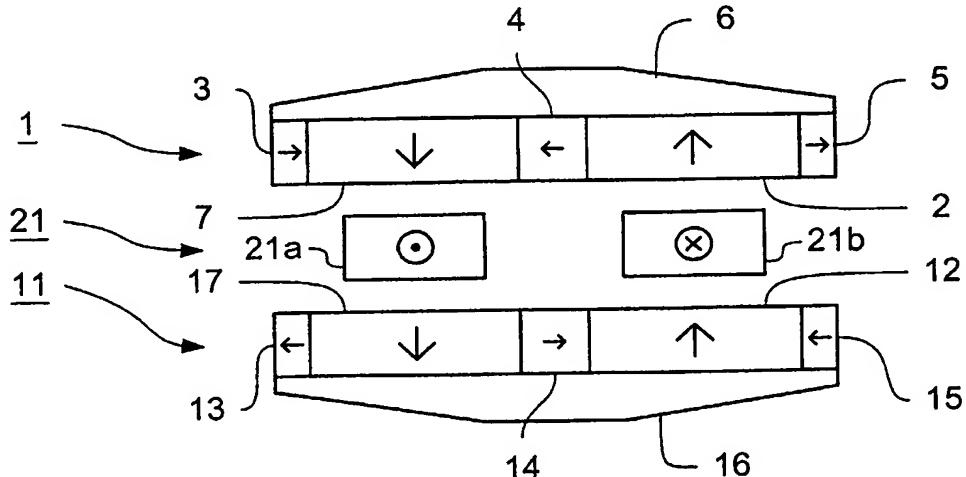
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(54) Lithographic apparatus and device manufacturing method

(57) A Lorentz actuator for providing a force between a first part and a second part of the apparatus, comprising a main magnet system, attached to a first part of the apparatus and providing a first magnetic field; a subsidiary magnet system, attached to said first part and arranged in a Halbach configuration, providing a

second magnetic field; and an electrically conductive element attached to a second part of the apparatus and arranged so as to produce a force between said first and second parts of the apparatus by interaction of an electric current carried by said electrically conductive element and the combination of the first and second magnetic fields.

Fig. 2a



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Description

[0001] The present invention relates to a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate; and
- a projection system for projecting the patterned beam onto a target portion of the substrate.

[0002] The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. An example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. The required matrix addressing can be performed using suitable electronic means. More information on such mirror arrays can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, which are incorporated herein by reference. In the case of a programmable mirror

array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.

5 - A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

10 For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0003] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a

20 single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper.

25 In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direc-

30 tion; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More information with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

[0004] In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered 35 by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then

undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

[0005] For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Twin stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

[0006] In such apparatus Lorentz actuators are typically used for the fine positioning of components such as the substrate table, which holds the substrate, and the mask table, which holds the mask. A critical issue in the use of Lorentz actuators in lithographic projection apparatus is the amount of heat generated in use by the coils of the Lorentz actuator. Any heat produced must be dissipated in order to prevent temperature changes in critical components that could lead to losses in the accuracy of the apparatus. It is therefore desirable to improve the efficiency of the Lorentz actuators.

[0007] In general Lorentz motors consist of an electrically conductive element, such as a coil, and a magnet assembly. The magnet assembly produces a magnetic field which interacts with a current flowing in the electrically conductive element to produce a force between the electrically conductive element and the magnet assembly in a direction perpendicular to the direction of the current flow and the magnetic field at that point. Typically the magnet assembly is comprised of at least one magnet on either side of the electrically conductive element to produce an approximately uniform magnetic field around the electrical conductor. Lorentz actuators do

not include any iron in the coils. The magnet assembly of a Lorentz actuator does, however, comprises a back iron, formed from a material with high magnetic saturation, located on the outward side of the magnets. The back iron is typically required to be large to prevent saturation and it constitutes a substantial part of the mass of the actuator and is a source of loss of efficiency in the motor.

[0008] It is an object of the present invention to provide a lithographic projection apparatus with an actuator having a back iron of reduced mass but no loss of performance of the actuator.

[0009] This and other objects are achieved according to the invention in a lithographic apparatus as specified in the opening paragraph, further comprising:

- a Lorentz actuator for producing a force between a first and a second part of the apparatus, comprising:

20 - a main magnet system, attached to said first part of the apparatus, providing a first magnetic field, substantially perpendicular to the direction of the force; and
 25 - an electrically conductive element attached to said second part of the apparatus and arranged so as to produce said force by interaction of an electric current carried by said electrically conductive element and the first magnetic field;

30 characterized in that the Lorentz actuator further comprises:

35 - a subsidiary magnet system, attached to said first part of the apparatus and arranged in a Halbach configuration, providing a second magnetic field substantially perpendicular to the first magnetic field.

[0010] This arrangement is advantageous since it increases the k-factor of the actuator (also referred to as the motor constant) which means that the force produced for a given flow of current through the coils is increased. It also reduces the size of the back iron required to prevent saturation. This therefore means that 45 the mass of back iron in the actuator will be reduced and will further improve the efficiency of the actuator since as the moving mass of the actuator is decreased the force required to produce a given acceleration is decreased. The combination of the effects results in a significant reduction in the current to effect a given acceleration which in turn reduces the amount of heat generated by the coils.

[0011] In a preferred embodiment of the present invention, the subsidiary magnet system comprises a first and a second subsidiary magnet and the main magnet system comprises a main magnet, at least a part of which is located between the two subsidiary magnets. The magnets are orientated such that the magnetic po-

larization of the first subsidiary magnet is substantially anti-parallel to that of the second subsidiary magnet and the magnetic polarization of the main magnet is substantially perpendicular to those of the two subsidiary magnets.

[0012] In a yet further preferred embodiment of the present invention, the Lorentz actuator comprises two magnet assemblies. The first magnet assembly comprises a first main magnet system sub-assembly and a first subsidiary magnet system sub-assembly and the second magnet assembly comprises a second main magnet system sub-assembly and a second subsidiary magnet system sub-assembly. At least a part of the electrically conductive element is located between the first and second magnet assemblies.

[0013] In a yet further preferred embodiment of the present invention, each magnet assembly comprises first and second main magnets, orientated such that their magnetic polarizations are substantially anti-parallel to each other. The magnet assemblies further comprise first, second and third subsidiary magnets arranged such that at least a portion of the first main magnet is located between the first and second subsidiary magnets and at least a portion of the second main magnet is located between the second and third subsidiary magnets. The electrically conductive element comprises a first part, located between the first main magnet of the first magnet assembly and the first main magnet of the second assembly, and a second part, located between the second main magnet of the first magnet assembly and the second main magnet of the second magnet assembly. The electrically conductive element is arranged such that, when it conducts electric current, the direction of the electric current in the first part is substantially anti-parallel to the direction of the electric current in the second part.

[0014] According to a further aspect of the invention there is provided a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material, characterized by providing a Lorentz actuator, comprising:
 - a main magnet system, attached to a first part of the apparatus, providing a first magnetic field;
 - a subsidiary magnet system, attached to said first part and arranged in a Halbach configuration, providing a second magnetic field; and

- an electrically conductive element attached to a second part of the apparatus and arranged so as to produce a force between said first and second parts of the apparatus by interaction of an electric current carried by said electrically conductive element and the combination of the first and second magnetic fields;

and providing an electric current said electrically conductive element.

[0015] Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

[0016] In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, e.g. having a wavelength in the range 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[0017] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;
 Figure 2a shows, in cross-section, the configuration of an actuator according to the present invention;
 Figure 2b shows the magnetic field lines calculated for the configuration of Figure 2a;
 Figure 3 shows the configuration of Figure 2a in perspective; and
 Figure 4 shows, in cross-section, the configuration of an alternative actuator according to the present invention.

[0018] In the Figures, corresponding reference symbols indicate corresponding parts.

Embodiment 1

[0019] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

a radiation system Ex, IL, for supplying a projection beam PB of radiation (e.g. EUV radiation). In this

particular case, the radiation system also comprises a radiation source LA; a first object table (mask table) MT provided with a mask holder for holding a mask MA (e.g. a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL; a second object table (substrate table) WT provided with a substrate holder for holding a substrate W (e.g. a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL; a projection system ("lens") PL (e.g. a lens group) for imaging an irradiated portion of the mask MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

As here depicted, the apparatus is of a transmissive type (*i.e.* has a transmissive mask). However, in general, it may also be of a reflective type, for example (with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0020] The source LA (e.g. Hg lamp or excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after having traversed conditioning means, such as a beam expander Ex, for example. The illuminator IL may comprise adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

[0021] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0022] The beam PB subsequently intercepts the mask MA, which is held on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and Interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object ta-

bles MT, WT will be realized with the aid of a long-stroke module (course positioning) and a short-stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0023] The depicted apparatus can be used in two different modes:

- 10 1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;
- 15 2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the y direction) with a speed v, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which M is the magnification of the lens PL (typically, $M = 1/4$ or $1/5$). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

[0024] Figure 2a shows a cross section of the actuator according to a preferred embodiment of the present invention. The same actuator is shown, in perspective, in Figure 3. In use, the actuator generates a force in a first direction (or its reverse) which may be used to drive a short-stroke drive module for positioning of the mask table MT or the substrate table WT. In Figure 2a this first direction is a horizontal direction within the plane of the Figure. The actuator consists of a first magnet sub-assembly 1, a second magnet sub-assembly 11 and a coil 21. The first and second magnet sub-assemblies 1, 11 define a space between them in a second direction, perpendicular to the first direction. The coil 21 is located in this space.

[0025] The combination of the first and second magnet sub-assemblies 1, 11 forms a magnet assembly that is mounted on the substrate table WT or the mask table MT to be driven by the actuator. The coil 21 is mounted on the long-stroke module (not shown) or, in the case of a mask table MT of a wafer stepper apparatus that does not have a long-stroke module (as described above), on a fixed portion of the apparatus.

[0026] Although the magnet assembly may alternatively be mounted on the long-stroke module and the coil on the substrate table or the mask table, the present configuration is preferred since it facilitates the provision of power and cooling to the coil.

[0027] The first magnet sub-assembly 1 is composed

of a first main magnet 2, a second main magnet 7, a first subsidiary magnet 5, a second subsidiary magnet 4 and a third subsidiary magnet 3. The second magnet sub-assembly 11 correspondingly has a first main magnet 12, a second main magnet 17, a first subsidiary magnet 15, a second subsidiary magnet 14 and a third subsidiary magnet 13. In a preferred arrangement, the main magnets are permanent magnets consisting of Ni-coated Vacodynam722HR having a magnetic remanence of $B_r=1.47$ Tesla (T) and the subsidiary magnets consist of Ni-coated Vacodynam362TP with a magnetic remanence of $B_r=1.30$ Tesla (T) and high coercive field strength as produced by Vacuumsschmelze GmbH.

[0028] Each of the magnet sub-assemblies is arranged such that the component magnets are adjacent to one another in the first direction, as defined above. In this arrangement, a subsidiary magnet is located on either side of each of the main magnets. For example, the first main magnet 2 of the first magnet sub-assembly 1 is located between the first subsidiary magnet 5 and the third subsidiary magnet 4 of the first magnet sub-assembly. Similarly, the second main magnet 7 of the first magnet sub-assembly 1 is located between the second subsidiary magnet 4 and the third subsidiary magnet 3. The second magnet sub-assembly is arranged in a similar fashion such that, in the complete magnet assembly, the corresponding magnets in the two sub-assemblies 1, 11 are facing each other.

[0029] Each of the magnet sub-assemblies has a back iron 6, 16, respectively. In each sub-assembly the back iron is located on the other side of the magnets to the space that is defined between the magnet sub-assemblies. The back iron adjoins each of the main and each of the subsidiary magnets in the sub-assembly and preferably entirely covers the surfaces of the magnets. The back iron also preferably tapers, at least partly, in the direction away from the space between the magnet sub-assemblies. The back iron is preferably formed from CoFe.

[0030] The coil 21 (SP2 in Fig. 1), having two sides 21a and 21b (as shown in Figure 2a), is located between the magnet sub-assemblies 1, 11 and is comprised of orthocyclic windings. The coil is arranged such that, where it is located between the first and second magnet sub-assemblies, the wires that it is composed from are perpendicular to both the first and second directions defined above. As shown in Figure 2a, the wires are orientated in a direction perpendicular to the plane of the Figure.

[0031] The magnets in the first and second magnet sub-assemblies 1, 11 are orientated such that the magnetic polarizations of the first main magnet 2 in the first magnet sub-assembly is parallel to the magnetic polarization of the first main magnet 12 of the second magnet sub-assembly and in a direction perpendicular to the first direction, defined above, namely perpendicular to the direction of the force generated by the actuator. The second main magnets 7, 17 are orientated such that

their magnetic polarizations are parallel to one another and anti-parallel to the magnetic polarizations of the first main magnets 2, 12.

[0032] The subsidiary magnets of the magnet sub-assemblies are arranged in the so-called Halbach configuration. The subsidiary magnets are orientated such that their magnetic polarizations are perpendicular to those of the main magnets. As stated above, each of the main magnets is located between two subsidiary magnets of the magnet sub-assembly. These pairs of subsidiary magnets are orientated such that their magnetic polarizations are anti-parallel to one another. Furthermore, the pairs of corresponding subsidiary magnets in the first and second magnet sub-assemblies (which, as described above, face each other across the separation between the two magnet sub-assemblies), for example the first subsidiary magnet 5 of the first magnet sub-assembly and the first subsidiary magnet 15 of the second magnet sub-assembly, are also arranged such that their magnetic polarizations are anti-parallel to one another.

[0033] The resulting magnetic field that this configuration produces, as shown in Figure 2b, regions of approximately uniform magnetic field between the two pairs of main magnets. The two sides of the coil 21a, 21b are located in these regions. When an electric current is passed through the coil, the current flow through the two sides of the coil is in opposite directions. Therefore, since the directions of magnetic field in the two regions in which the two sides of the coil 21a, 21b are located are also opposite, the force exerted on the two sides of the coil is in the same direction (perpendicular to both the magnetic field and the current flow).

[0034] Figure 4 shows, in cross-section, the configuration of an alternative actuator of the present invention. This configuration comprises two coils 81, 82. Therefore the structure of the magnet sub-assemblies 51, 71 is different to those depicted in Figure 2a. Each magnet sub-assembly is comprised of a first main magnet 57, 77, a second main magnet 55, 75, a third main magnet 53, 73, first subsidiary magnet 56, 76, second subsidiary magnet 54, 74 and, as in the previous configuration, a back iron 52, 72.

[0035] The main magnets are orientated such that the magnetic polarization of the first main magnet 57 of the first magnet sub-assembly is parallel to that of the first main magnet 77 of the second magnet sub-assembly, the magnetic polarization of the second main magnet 55 of the first magnet sub-assembly is parallel to that of the second main magnet 75 of the second magnet sub-assembly, and the magnetic polarization of the third main magnet 53 of the first magnet sub-assembly is parallel to that of the third main magnet 73 of the second magnet sub-assembly. As in the configuration of Figure 2a, all of the main magnets are orientated such that their magnetic polarizations are perpendicular to the direction of the force produced by the actuator. In addition, the first main magnets 57, 77 and the third main mag-

nets 53, 73 are orientated such that their magnetic polarizations are anti-parallel to those of the second main magnets 55, 75.

[0036] The first subsidiary magnets 56, 76 are located between the first main magnets 57, 77 and the second main magnets 55, 75 and the second subsidiary magnets 54, 74 are located between the second main magnets 55, 75 and the third main magnets 53, 73. Consequently, the second main magnets are located between the subsidiary magnets of each magnet sub-assembly.

[0037] The subsidiary magnets of the first magnet sub-assembly 51 are orientated such that their magnetic polarizations are mutually anti-parallel and perpendicular to the magnetic polarization of the second main magnet 55. The subsidiary magnets of the second magnet sub-assembly are orientated in corresponding fashion and such that the magnetic polarization of the first subsidiary magnet 56 of the first magnet sub-assembly 51 is anti-parallel to the magnetic polarization of the first subsidiary magnet 76 of the second magnet sub-assembly 71 and the magnetic polarization of the second subsidiary magnet 54 of the first magnet sub-assembly 51 is anti-parallel to the magnetic polarization of the second subsidiary magnet 74 of the second magnet sub-assembly 71. The resulting magnetic field between the main magnets of the two magnet sub-assemblies is approximately uniform.

[0038] The coils are arranged such that the first portion 81a of the first coil 81 is located between the third main magnets 53, 73, the second portion 81b of the first coil 81 and the first portion 82a of the second coil 82 are located between the second magnets 55, 75 and the second portion 82b of the second coil 82 is located between the third main magnets 57, 77. When an electric current is passed through the coils 81, 82, the directions of the flow of electric current in the second part 81b of the first coil 81 and the first part 82a of the second coil 82 are mutually parallel and are anti-parallel to the directions of the flow of electric current in the first part 81a of the first coil 81 and the second part 82b of the second coil 82. Since the direction of the magnetic field between the second main magnets 55, 75 is opposite to the directions of the magnetic field between the first main magnets 57, 77 and the second main magnets 53, 73, the forces produced on each of the parts 81a, 81b, 82a, 82b of the coils (in a direction perpendicular to both the direction of the flow of current and the magnetic field) are in the same direction.

[0039] Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

Claims

1. A lithographic projection apparatus comprising:

- a radiation system for providing a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;

- a substrate table for holding a substrate;
- a projection system for projecting the patterned beam onto a target portion of the substrate; and
- a Lorentz actuator for producing a force between a first and a second part of the apparatus, comprising:

- a main magnet system, attached to said first part of the apparatus, providing a first magnetic field, substantially perpendicular to the direction of the force; and
- an electrically conductive element attached to said second part of the apparatus and arranged so as to produce said force by interaction of an electric current carried by said electrically conductive element and the first magnetic field;

characterized in that the Lorentz actuator further comprises:

- a subsidiary magnet system, attached to said first part of the apparatus and arranged in a Halbach configuration, providing a second magnetic field substantially perpendicular to the first magnetic field.

2. A lithographic projection apparatus according to Claim 1, wherein said subsidiary magnet system comprises two subsidiary magnets; said main magnet system comprises a main magnet, at least a part of which is located between said two subsidiary magnets; the magnetic polarizations of the subsidiary magnets being orientated substantially mutually anti-parallel and substantially perpendicular to the magnetic polarization of the main magnet.

3. A lithographic projection apparatus according to Claim 1 or 2, wherein said main magnet system is comprised of a first and a second main magnet system sub-assemblies; said subsidiary magnet system is comprised of a first and a second subsidiary magnet system sub-assemblies; and at least a part of said electrically conductive element is located between a first magnet assembly, comprised of said first magnet system sub-assemblies, and a second magnet assembly, comprised of said second magnet system sub-assemblies.

4. A lithographic projection apparatus according to Claim 3, wherein said part of said electrically conductive element is orientated such that the direction

of the electric current carried by it is substantially perpendicular to the direction of the force between the two parts of the apparatus.

5. A lithographic projection apparatus according to Claim 3 or 4, wherein said main magnet system comprises at least one magnet that is orientated such that its magnetic polarization is substantially perpendicular to the direction of the force between the two parts of the apparatus and substantially perpendicular to the direction of the electric current carried by said part of the electrically conductive element.
6. A lithographic projection apparatus according to any one of Claims 3 to 5, wherein each said main magnet system sub-assembly comprises a first and a second main magnet orientated such that their magnetic polarizations are substantially mutually anti-parallel.
7. A lithographic projection apparatus according to Claim 6, wherein each of said subsidiary magnet sub-assemblies comprises a first, second and a third subsidiary magnet; and each of said subsidiary magnet assemblies is arranged such that:
 - at least a part of said first main magnet is located between the first and second subsidiary magnets;
 - at least a part of said second main magnet is located between the second and the third subsidiary magnets;
 - the first and second subsidiary magnets are orientated such that their magnetic polarizations are substantially mutually anti-parallel and substantially perpendicular to that of the first main magnet; and
 - the second and third subsidiary magnets are orientated such that their magnetic polarizations are substantially mutually anti-parallel and substantially perpendicular to that of the second main magnet.
8. A lithographic projection apparatus according to Claim 6 or 7, wherein the electrically conductive element comprises:
 - a first part, located between the first main magnets of the first and second main magnet system sub-assemblies; and
 - a second part, located between the second main magnets of the first and second main magnet system sub-assemblies;

and the electrically conductive element is arranged such that, when it conducts electric current, the direction of the electric currents in the first and second

parts are substantially mutually anti-parallel.

9. A lithographic projection apparatus according to any one of Claims 3 to 5, wherein each said main magnet sub assembly comprises a first, second and a third main magnet, arranged such that at least a part of said second main magnet is located between said first and third main magnets; and said main magnets are orientated such that the magnetic polarization of said second main magnet is substantially anti-parallel to that of the first and the third main magnets.
10. A lithographic projection apparatus according to Claim 9, wherein each of said subsidiary magnet sub-assemblies comprises a first and a second subsidiary magnet; and each of said subsidiary magnet assemblies is arranged such that:
 - at least a part of said second main magnet is located between the first and second subsidiary magnets; and
 - the first and second subsidiary magnets are orientated such that their magnetic polarizations are substantially mutually anti-parallel and substantially perpendicular to that of the second main magnet.
11. A lithographic projection apparatus according to Claim 9 or 10, wherein the electrically conductive element comprises:
 - a first part, located between the first main magnets of the first and second main magnet system sub-assemblies;
 - a second and a third part, located between the second main magnets of the first and second main magnet system sub-assemblies; and
 - a fourth part, located between the third main magnets of the first and second main magnet system sub-assemblies;

and the electrically conductive element is arranged such that, when it conducts electric current, the direction of the electric currents in the first and the fourth parts are substantially mutually parallel and are substantially anti-parallel to the direction of the electric currents in the second and the third parts of the electrically conductive element.
12. A lithographic projection apparatus according to any one of Claims 3 to 11, wherein at least one of said first and second main magnet system sub-assemblies further comprises a back iron, located such that the magnets of said sub-assembly are located between the back iron of the magnet sub-assembly and said electrically conductive element.

13. A lithographic projection apparatus according to any one of the preceding Claims, wherein the support structure comprises a mask table for holding a mask.

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14. A lithographic projection apparatus according to any one of the preceding Claims, wherein the radiation system comprises a radiation source.

15. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target portion of the layer of radiation-sensitive material;

characterized by providing a Lorentz actuator, comprising:

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- a main magnet system, attached to a first part of the apparatus, providing a first magnetic field;
- a subsidiary magnet system, attached to said first part and arranged in a Halbach configuration, providing a second magnetic field; and
- an electrically conductive element attached to a second part of the apparatus and arranged so as to produce a force between said first and second parts of the apparatus by interaction of an electric current carried by said electrically conductive element and the combination of the first and second magnetic fields;

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and providing an electric current said electrically conductive element.

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Fig. 1

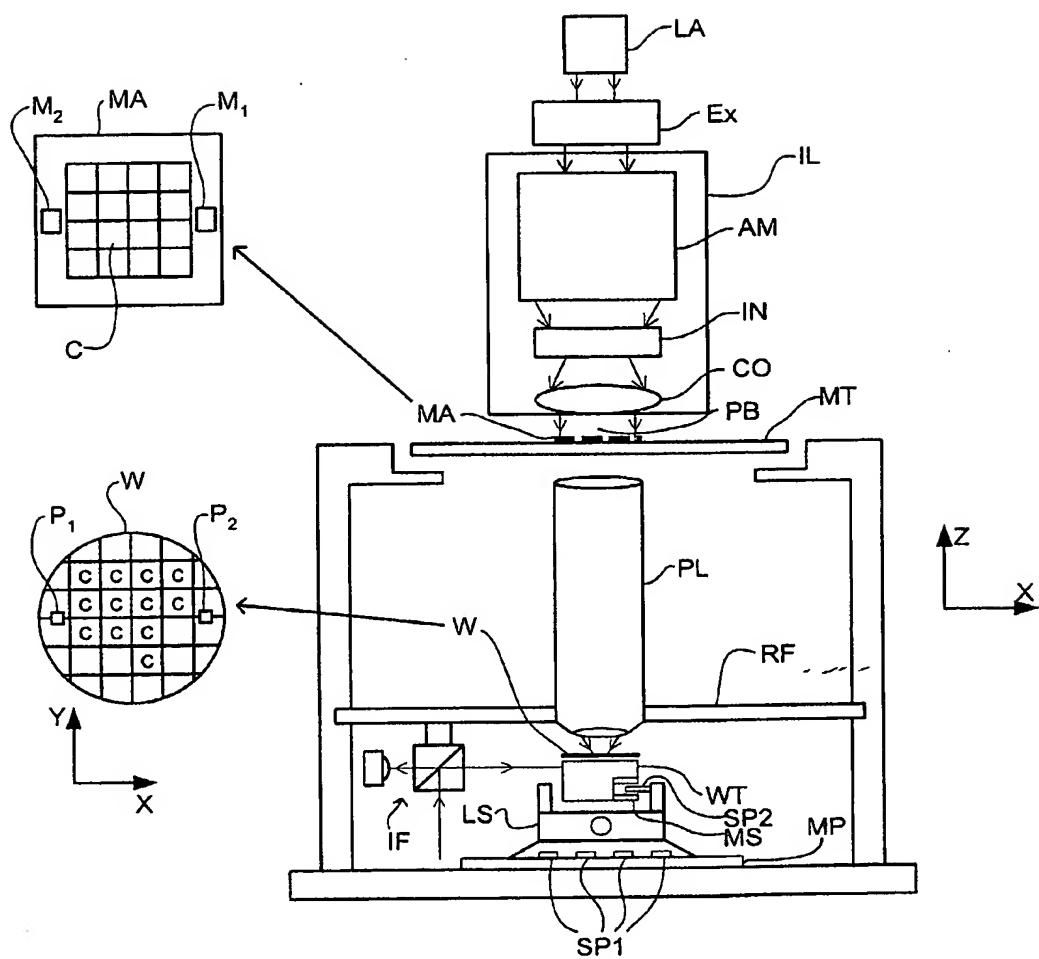


Fig. 2a

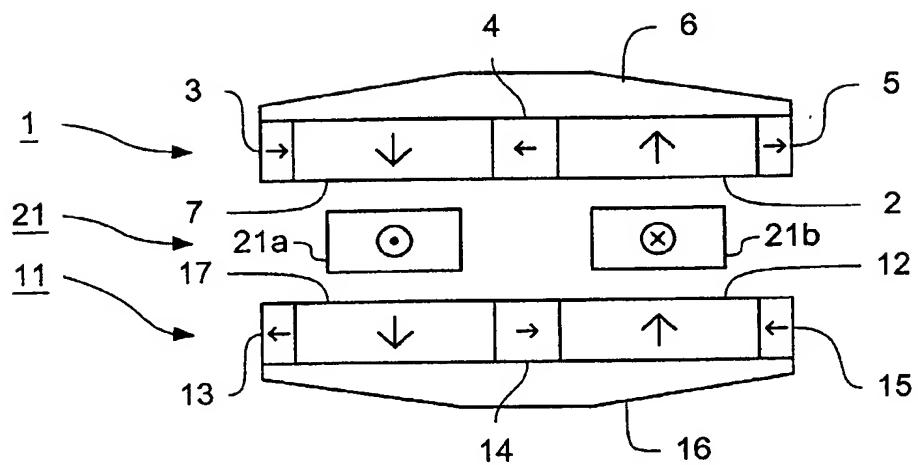


Fig. 2b

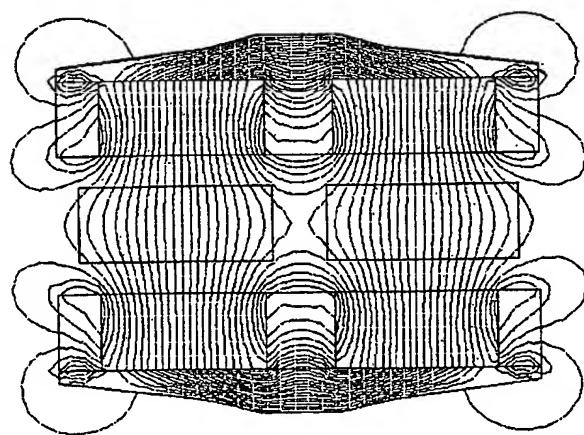


Fig. 3

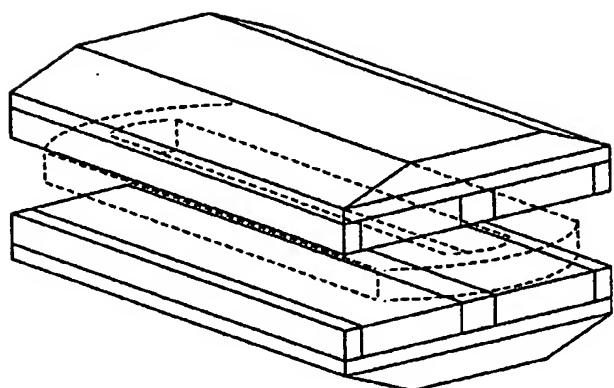
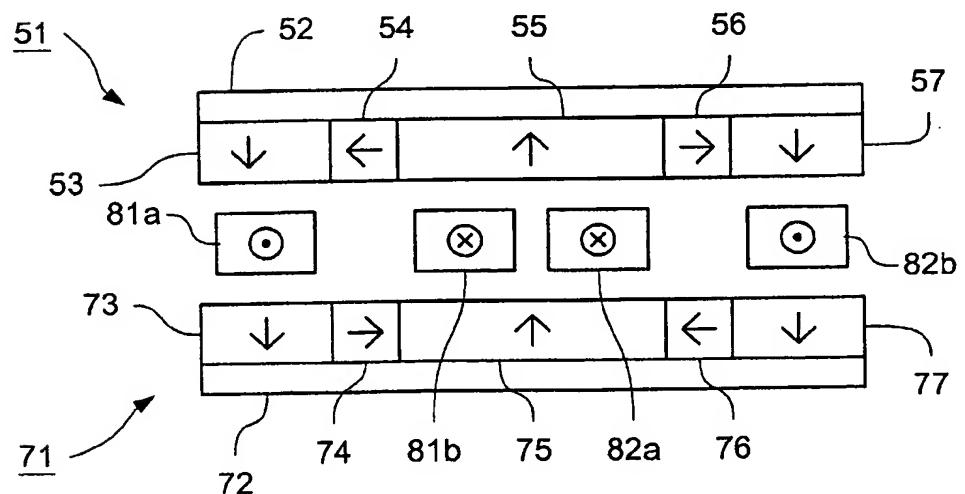


Fig. 4





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EUROPEAN SEARCH REPORT

Application Number
EP 02 25 5759

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